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Abstract: The late Holocene pollen stratigraphy of Lake Louise, Manitoba, consists of two zones, zone 1 from 35 cm to 64.5 cm deep, and zone 2 extending from 0 to 30 cm deep; the transition from zone 1 to zone 2 occurs between sampling points at depths of 30 cm and 35 cm. Zone 1 predates the establishment of European agricultural practices and is interpreted to resemble an open oak savannah community, but with the oak present marginal to the lake and nearby Red River channel rather than being dispersed as an open forest. Within zone 2, the rise at 30 cm of Ambrosia, Liguliflorae, Cruciferae, and cereal species of Gramineae is interpreted to represent large-scale land disturbance caused by the introduction of European agricultural practices during the late 1870s and early 1880s. Chronological data suggest an increase of about ten times in the sedimentation rate in Lake Louise within zone 2 relative to zone 1.

Résumé : La stratigraphie pollinique de l'Holocène supérieur du lac Louise (Manitoba) comporte deux zones, soit la zone 1, de 35 à 64,5 cm de profondeur, et la zone 2, de 0 à 30 cm de profondeur. La transition entre la zone 1 et la zone 2 se situe entre des points d'échantillonnage à des profondeurs de 30 à 35 cm. La zone 1 est antérieure à la mise en place des pratiques agricoles européennes et est interprétée comme ressemblant à un peuplement clair de savane à chênes. Cependant, les chênes se trouvent au bord du lac et près du lit de la rivière Red et ne sont pas dispersés en forêt claire. Dans la zone 2, la présence à 30 cm d'Ambrosia, de Liguliflorae, de Cruciferae et de céréales de la famille des graminées est interprétée comme représentant des perturbations à grande échelle des terres causées par l'introduction de pratiques agricoles européennes vers la fin des années 1870 ou le début des années 1880. D'après les données chronologiques, l'accroissement du taux de sédimentation au lac Louise serait d'environ 10 fois supérieur dans la zone 2 que dans la zone 1.

INTRODUCTION

The Red River flows northwards along the gently sloped plain of the Red River valley from southern North Dakota–Minnesota to Lake Winnipeg, Manitoba (Fig. 1). The areas adjacent to the river are prone to flooding from snowmelt runoff. Numerous floods, some causing major disasters, have occurred in the Red River valley, most recently, in 1997 (*see* Bumsted, 1997; Rannie, 1998). In response to the flood hazard, an array of flood protection infrastructure has been constructed in Manitoba over the past several decades, including linear dykes, ring-dykes, elevated pads, the Portage Diversion, and, most ambitiously, the Red River Floodway, which diverts Red River flow around Winnipeg. Because of deficiencies in flood protection during the 1997 flood as well as concerns about larger floods in the future, the flood protection infrastructure in the Red River valley is currently being upgraded or considered for possible upgrading (Topping and Caligiuri, 1999; International Joint Commission, 1999, 2000).

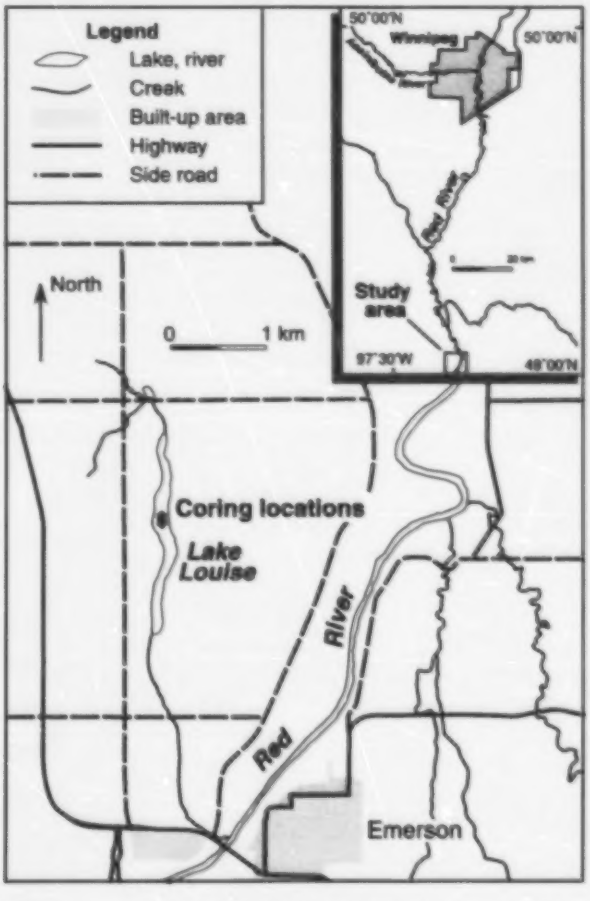

Figure 1. *Map of Lake Louise, Manitoba, showing the coring locations. The inset map shows the location of Lake Louise within the Red River valley.*

The Geological Survey of Canada and Manitoba Geological Survey are currently undertaking a multidisciplinary project that utilizes stratigraphical and dendrochronological evidence to reconstruct a paleoflood record for the Red River (*see* Brooks et al., 1999; St. George et al., 1999). The goal of this project is to identify significant flood events that predate early nineteenth century historical accounts of Red River flooding (*see* Rannie, 1998, 1999). One aspect of this research is the investigation of sediments contained within small ox-bow or channel-scar lakes located close to the river. These lakes are situated within the Red River flood zone and periodically receive an influx of river water during elevated stages, as mentioned below. A paleoflood record can potentially be reconstructed from the deposits in these lakes.

The purpose of this paper is to report the late Holocene pollen stratigraphy of a 64.5 cm long composite core from Lake Louise, Manitoba. Based on the pollen record, the depth ranges that pre- and postdate large-scale land disturbance by European settlers are identified and changes in the late Holocene sedimentation rates into the lake are discussed. These results supplement other work currently underway that is examining the diatom and thecamoebian stratigraphy of the lake deposits.

STUDY AREA

Lake Louise is a shallow perennial lake, up to 2.4 m deep, that is located near Emerson, Manitoba, 2.5 km north of the Canada–U.S.A. border, and 2 km west of the Red River (Fig. 1). The lake is elongated and slightly sinuous in shape, 2050 m long and up to 175 m wide (Fig. 1.2). In the immediate vicinity, the lake is bordered by a narrow stand of deciduous trees on its east side, mixed deciduous and coniferous trees to the north, and cultivated cereal fields on the west and south sides (Fig. 2). Based on the eutropic status classification for total phosphorus of Wetzel (1983), Lake Louise is eutrophic at least during the late spring and early summer months, as revealed by water samples collected in May 1998 and June 1999 (C. Prévost, pers. comm., February 2000; Table 1).

Aerial photograph interpretation reveals that the lake is situated within a palaeochannel of the Red River. It is not known when the palaeochannel was abandoned by the Red River, but the geomorphology of the general area suggests that this has not occurred in the late Holocene. Because Lake

Table 1. Total phosphorus in grab water samples from Lake Louise, Manitoba.

Sampling date	Concentration (mg/L)[a]
May 24, 1998	0.09
	0.11
June 28, 1999	0.09

[a]Analysis by Robert O. Pickard Centre Laboratory of the Regional Municipality of Ottawa-Carleton

Figure 2.

Oblique aerial photograph of Lake Louise, looking towards the northeast (photograph taken June 14, 1997).

Louise is situated within a palaeochannel, it regularly receives an influx of river waters during elevated river stages. The threshold of discharge when the incursion of river waters into Lake Louise begins is not known specifically; however, we have observed it underway in April 1999 at a discharge of about 1300 m^3/s, a flow which corresponds to a return period of 8–9 years at the nearby 'Red River at Emerson' streamflow station (based on Manitoba Water Resources data).

METHODS

Lake Louise was cored in June of 1998 and 1999 from a floating platform consisting of two rectangular boats connected together with steel rods, that was anchored securely to the lake bed. Core was obtained in each of those years from sampling sites situated over the deepest part of the lake (about 2.4 m deep; Fig. 1). A core, extending over the depth range of 28–64.5 cm, was collected in June 1998 using a Livingstone Corer (Livingstone, 1955). This depth range reflected an initial sampling strategy to focus on the deeper and older sediments in the lake bed. To sample the most recent sediment, a core was retrieved in June 1999 using a gravity corer (Glew, 1991) and spanned the depths 0–34 cm.

Samples 1 cm^3 were removed from the gravity core at 1 cm intervals to a depth of 30 cm. From the Livingstone core, 2 cm^3 samples were removed at depths of 35 cm and 40 cm, and then at depths of 40 cm, 50 cm, and 63 cm. The sample size was increased to 2 cm^3 because there was a rise in the clay content of the core sediments below 30 cm and it was anticipated that there might be a corresponding drop in pollen concentration. Hereafter, the composite core is referred to as LakeLouise–98-1.

Pollen preparation followed Faegri and Iversen (1963, *in* Faegri et al., 1989). Two tablets of *Lycopodium* (batch no. 938934) were added to the lake sediment samples contained within 15 mL centrifuge tubes. To concentrate the pollen grains, the samples were treated with a sequence of 10% HCl acid, 10% KOH base, 48% HF acid, acetolysis, and tertiary butanol. Finally, the samples were stored in silicone oil and mounted on slides for examination using a Leitz™ DMRB microscope at 400 magnification. The pollen counts are summarized in Figure 3.

RESULTS AND INTERPRETATIONS

The pollen spectra within core LakeLouise–98-1 consist of a diverse range of arboreal (tree) and nonarboreal (herbaceous and grass) pollen grains (Fig. 3). Based on this spectra, the stratigraphic sequence can be divided into two pollen zones. Zone 1 is stratigraphically older and extends from a depth of 64.5 cm to 35 cm while zone 2 spans the upper 30 cm of the core (depth range of 30–0 cm). It should be noted that the boundary between zones 1 to 2 occurs between the depths of 30 cm and 35 cm and thus is difficult to define specifically with a depth. The pollen spectra of the two zones are described and interpreted separately below, beginning with zone 1.

A high proportion of arboreal pollen, ranging from 55% to 72% (Fig. 3), characterizes the pollen content of zone 1. *Quercus* and *Pinus* are the most abundant tree pollens. Both experience a moderate change in relative abundance with decreased depth: *Pinus* increase from about 15% to 33% while *Quercus* decreases from about 25% to 17% (Fig. 3). There is a moderate representation of pollen from *Picea*, *Ulmus*, and *Betula* (5–10%), and lesser amounts of *Fraxinus*, *Tilia*, *Salix*, *Alnus rugosa*, and *Alnus crispa* (1–3%). Also present in zone 1 is a diverse range of herbaceous and aquatic pollen (Fig. 3). The most abundant herb pollens are *Artemisia*, *Ambrosia*, and Gramineae (5–10%) and Chenopodiaceae and Tubuliflorae (about 3–5%), all of which are herb or grass species.

A composite sample of a *Scirpus* seed and several charcoal fragments situated at a depth range of 64.5–63.5 cm, provides chronological information for zone 2. Dating of this

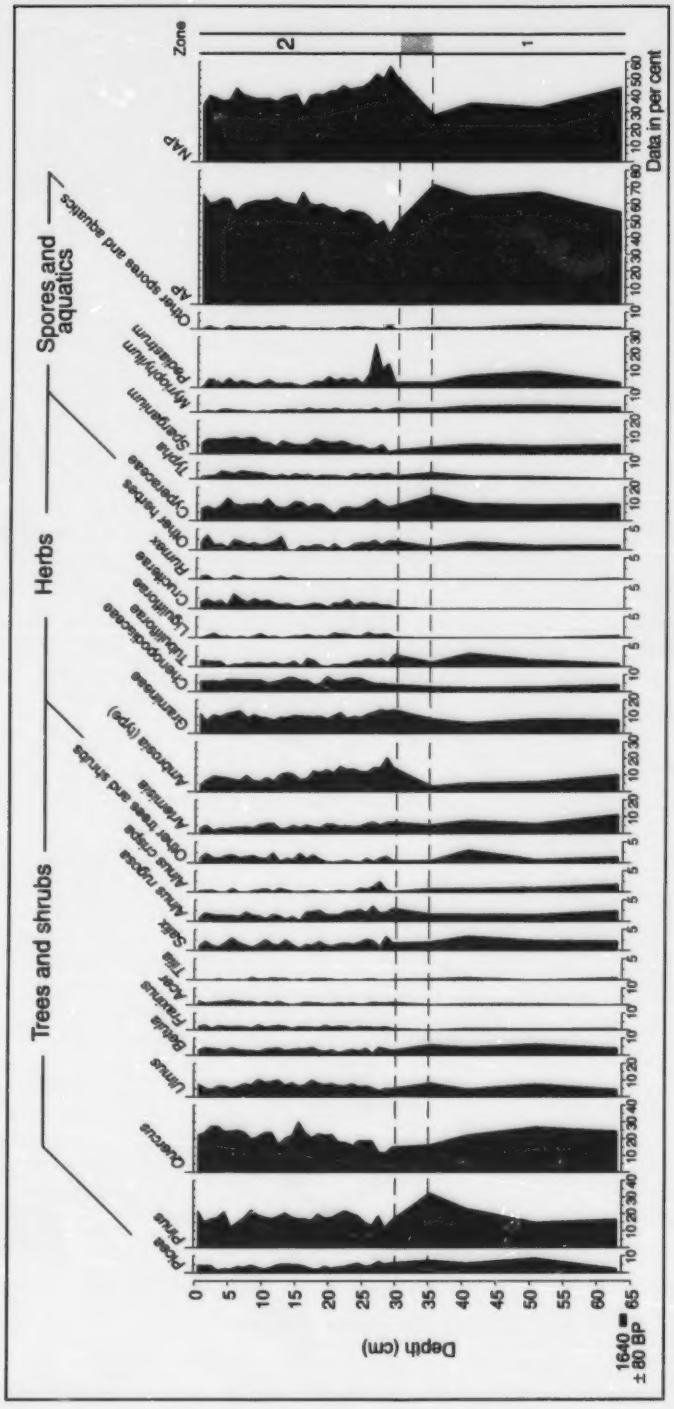

Figure 3. *Pollen stratigraphy of the core LakeLouise–98-1 from Lake Louise, Manitoba, showing the relative per cent abundance of individual species, cumulative abundance of arboreal (AP) and nonarboreal pollen grains (NAP), and the depth ranges of the two pollen zones. The grey area (right side of diagram) represents the depth range where the transition from zone 1 to zone 2 occurs.*

material using AMS techniques yielded a radiocarbon age of 1640 ± 80 BP (CAMS-52525), which represents a maximum age for the upper approximate 64 cm of the core.

Artemisia, *Ambrosia*, Gramineae, and Chenopodiaceae are "Prairie indicator" species (Baker et al., 1992) and thus are indicative of a grassland community in the area around the lake. The high relative abundance of *Quercus* pollen suggests the nearby presence of oak trees. *Acer*, *Ulmus*, *Fraxinus*, and *Alnus rugosa* are trees and shrubs that flourish in moist environments (Hosie, 1979; Jacobson and Engstrom, 1989). The margin of the lake would represent such an environment, as would any poorly drained wetlands located in the general area. Since zone 1 contains the organic materials that yielded the 1640 ± 80 BP radiocarbon date, it is interpreted to represent the natural vegetative community prior to European settlement.

The zone 1 assemblage is similar to one described by Ritchie and Lichti-Federovich (1968) from the Tiger Hills area, near Brandon, southwestern Manitoba. They suggest that this assemblage represents an open oak savannah community. Lake Louise has a similar assemblage, but it seems more likely to be an oak stand bordering the lake and the nearby Red River course, as is the case today, rather than being dispersed in an open forest throughout the general area. Consistent with this, Dawson (1875) described the grassland of the Red River valley as "absolutely treeless" except along the Red River and its tributaries which was fringed with trees. He mentions oak (*Quercus macrocarpa* var.), elm (*Ulmus americana*), poplar (*Populus tremuloides*), and ash-leaved maple (*Negundo aceroides*) by name as being the most abundant tree species. He also specifically remarks that "old portions of the river-channel, may frequently be observed forming ponds and small lakes on the prairie... [that are] fringed with trees, and are generally surrounded by a dense growth of reeds, and filled with rank aquatic vegetation (p. 266)".

Within zone 2, minor fluctuations in the relative abundance of the pollen are depicted in much more detail than in zone 1 on Figure 3 because of the much closer sampling interval (1 cm between 0 and 30 cm depths). Nevertheless, basic differences between the zones are readily evident. Between the depths of 35 cm and 30 cm, there is a marked rise in the relative abundance of nonarboreal pollen, which peaks at about 58% at a depth of 28 cm. This rise primarily reflects an increase in *Ambrosia* and Gramineae as well as a decrease in *Pinus* and a slight decrease in *Quercus*. At a depth of 29 cm depth, the relative abundance of Liguliflorae and Cruciferae begin to increase, although the relative abundance of pollen never exceeds several percentage points. Chenopodiaceae begins to rise at about a depth of 26 cm. By a depth of about 25 cm there is a slight drop in the relative abundance of *Ambrosia* and Gramineae compared to the depths of 29–27 cm. The relative abundance of *Quercus* is lowest at about 29–28 cm (10–11%), but it experiences a net rise between the depth interval of 27 cm and 0 cm. *Artemisia* is marginally lower in zone 2 than zone 1.

The zone 2 assemblage represents an important transformation in the landscape around Lake Louise. This is apparent from the rise in the relative abundance of *Ambrosia*, but also Liguliflorae and Cruciferae and the delayed rise in Chenopodiaceae (Fig. 3). A rise in *Ambrosia* is a well known indicator of land clearance and/or agricultural disturbance that has been observed across eastern North America (e.g. McAndrews, 1988). This has been observed regionally on the northeastern Prairies at, for example, Devils Lake, North Dakota (Jacobson and Engstrom, 1989), Tiger Hills, Manitoba (Ritchie and Lichti-Federovich, 1968), and Clear Lake, Iowa (Baker et al., 1992). The rise in *Ambrosia* at Lake Louise is also interpreted to represent land disturbance by European settlers. Of note, the rise in *Ambrosia* may be more abrupt than is depicted in Figure 3, but the detail of this rise is obscured because of the 5 cm sampling interval between the depths of 30 cm and 40 cm.

The land disturbance hypothesis is supported by the change of the relative abundance of pollen within Gramineae family, whereby the pollen from cereal species can be differentiated from wild grasses species on the basis of pollen grain size larger or smaller than 37 µm, respectively (Moore et al., 1991). As depicted in Figure 4, there is a marked rise in the proportion of pollen grains larger than or equal to 37 µm between the depths of 35 cm and 30 cm. Species of cereals that could be represented by this rise include *Avena-Triticum* group (>40 µm), *Hordeum* group (32–45 µm), and *Secale* (40–60 µm).

Although we have no radiocarbon age from this portion of the core, zone 2 is interpreted to represent the period after large-scale disturbance in the landscape by the introduction of European agricultural practices. It almost certainly extents back to the late 1870s–early 1880s when large-scale settlement occurred in the Lake Louise–Emerson area (McClelland, 1975); however, the initial settlement in the Lake Louise–Emerson area dates back to 1801 when a Hudson's Bay Company post was established on the west side of the Red River just south of the Canada–U.S.A. border, to compete with trading posts located at Pembina approximately 3 km south, established at about the same time (McClelland, 1975). Pembina, however, remained a minor settlement over the next several decades as Hind (1860) mentions that the population in 1857 did not "...number more than 100 souls." (p. 157). Since its earliest days, Pembina was a stop on the route taken by settlers traveling northwards by land to the Selkirk settlement at present-day Winnipeg. The trail between Pembina and the Selkirk settlement passed along the west side of the Red River close to Lake Louise (*see* Warkentin and Ruggles, 1970). Occupants of Pembina, settlers, and travelers likely disturbed the natural vegetation in the area as well as adjacent to the trail through, for example, the grazing of animals, the collection of wood for fuel and construction, limited cultivation, and the harvesting of prairie grass. The land disturbance between 1800 and the 1870s–1880s, however, was small-scale compared to post-1880 as Macoun (1882) describes that "[Prior] to 1874, the site of present Emerson was merely a prairie with small cultivated patches..." (p. 474). If this land disturbance caused

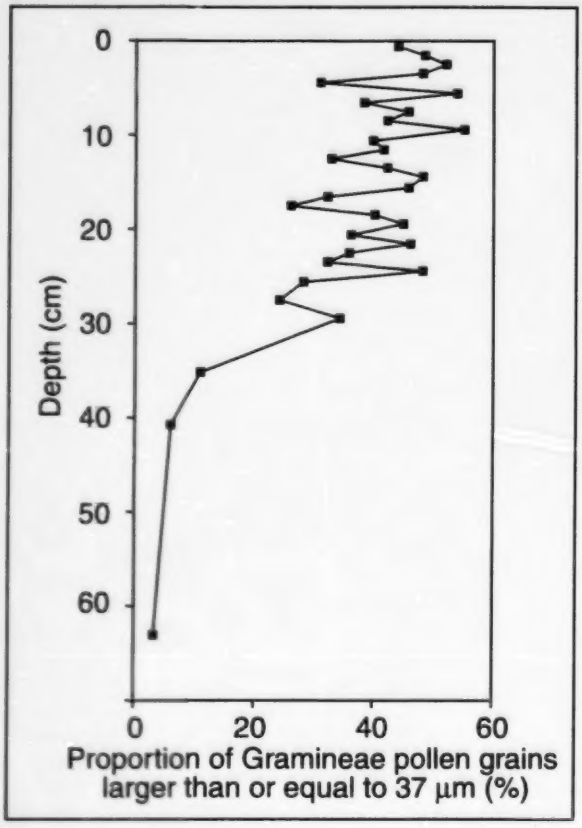

Figure 4. *Graph showing the proportion of pollen grains larger than 37 µm within the Gramineae family at various depths within core LakeLouise–98-1. Following the interpretation of Moore et al. (1991), pollen with a diameter of larger than or equal to 37 µm are considered to represent predominately cereal species while grains less than 37 µm are predominately from wild grass species.*

significant changes to the vegetation in the landscape, the details of this fall are between the sampling depths of 35 cm and 30 cm.

The decrease in arboreal pollen that occurs between depths of 35 cm and 28 cm also probably reflects the activities of the early to mid-nineteenth century settlers and travelers, who would have cut wood for heating and construction purposes. A later and probably more substantial impact on the trees in the area was caused by steamboat traffic along the river that began in 1859. The site of the Hudson's Bay Company post at Emerson served as an important refueling point for steamboats (Carlson and Masterson, 1950). Dawson (1875) mentions that considerable logging had occurred to forests along the river and that steamboats were the largest consumers. The net rise in arboreal pollen above a depth of 27 cm may reflect the regrowth of the trees after the steamboats were fully superseded by trains in the mid-1880s (Carlson and Masterson, 1950), construction materials became available from outside the region, and local wood decreased in importance as a fuel source.

DISCUSSION

Although there is only a single radiocarbon date from the core, it is apparent from the interpretation of the two zones that there is a substantial change in sedimentation rate within Lake Louise. The organic materials that yielded the 1640 ± 80 BP radiocarbon date were situated at a depth of 64.5–63.5 cm. Following Stuiver and Reimer (1993), the calibrated age of this radiocarbon date is 420 (340–540) cal AD (calibrated years). Zone 2, which is interpreted to correspond to the period after the large-scale introduction of European agricultural practices in the area, extends over a depth range from 30 cm to 0. While the exact age range of zone 2 is not known, a reasonable age estimate for the base of the zone is AD 1880, corresponding to the approximate beginning of large-scale settlement in the Emerson–Pembina area, as discussed above.

Based on the 420 (340-540) cal AD radiocarbon date and AD 1880, the sediment between the depths of 64 cm and 30 cm accumulated within a period of about 1380 years. The average rate of aggradation over this period is 0.24 mm/year. By comparison, the average rate of aggradation for the upper 30 cm of the core, the period from AD 1800 to AD 1999 is 2.5 mm/year. This recent rate of aggradation is about ten times higher than for the period predating AD 1880. Even considering a greater compaction of the lake sediment with increasing depth and that the 420 (340-540) cal AD radiocarbon date is a maximum age for the upper 64.5 cm of the lake bed, the post-1880 sedimentation rate represents a significant increase in sediment supply to Lake Louise.

The major increase in sedimentation above 30 cm has probably occurred for a couple of reasons. It likely reflects the impact of the introduction of large-scale agriculture in the immediate area of Lake Louise. Cultivated ground is more vulnerable to erosion from runoff (rainfall or snow melt) than ground supporting a continuous and stable grassland community with isolated tree stands. Some of the sediment delivered to Lake Louise probably also originated directly from the Red River and was carried into the lake basin as suspended load during high river stages. Indicative of this in the contemporary environment, sediment layers approximately 1.5 cm, 2 cm, and 2 cm thick were observed in gravity cores following the 1997, 1998, and 1999 freshet flows, respectively (C. Prévost, pers. comm., February 2000). The 1997, 1998, and 1999 freshets were all of sufficient magnitude to generate overbank flow from the Red River through the Lake Louise basin; the 1997 freshet was the largest Red River flow since 1852. Considering that large-scale agriculture has also been introduced at the regional scale of the Red River drainage basin, this likely has produced an increased suspended sediment load for the river in the period postdating settlement. This, in turn, has resulted in more sediment being carried into the lake basin during flood years than would have been the case in the landscape prior to European settlement.

CONCLUSIONS

The 64.5 cm deep, composite core LakeLouise–98-1 can be divided into two zones based on the pollen stratigraphy. Zone 1 extends over the depth range of 64.5–35 cm deep and consists of pollen representing a vegetation community that predates large-scale disturbance in the landscape by the introduction of European agricultural practices. This pollen assemblage is consistent with an open oak savannah community, but likely reflects oak growing along the margins of the lake and nearby Red River channel course rather than being dispersed in an open forest throughout the general area. Zone 2, extending from a depth of 30–0 cm, represents the period of major European settlement and is marked by a rise in *Ambrosia*. The transition between zones 1 and 2 occurs between sampling intervals at depths of 35 cm and 30 cm.

The pollen stratigraphy in combination with a radiocarbon date from the base of the core suggests that the sedimentation postdating AD 1880 was about ten times greater than the rate prior to AD 1880. This increase in sedimentation rate likely reflects greater erosion in the landscape due to the large-scale introduction and continued usage of European agricultural practices.

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